A Community Terrain-Following Ocean Modeling System

Hernan G. Arango
Institute of Marine and Coastal Sciences
Rutgers University
71 Dudley Road
New Brunswick, NJ 08901-8521, USA
phone: (732) 932-6555 x266 fax: (732) 932-6520 email: arango@marine.rutgers.edu

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http://myroms.org
http://ocean-modeling.org

LONG-TERM GOALS

The long-term technical goal is to design, develop and test the next generation primitive equation, Terrain-following Ocean Modeling System (TOMS) for high-resolution scientific and operational applications. This project will improve the ocean modeling capabilities of the U.S. Navy for relocatable, coastal, coupled atmosphere-ocean forecasting applications. It will also benefit the ocean modeling community at large by providing the current state-of-the-art knowledge in physics, numerical schemes, and computational technology.

OBJECTIVES

The main objective is to produce a tested expert Terrain-following Ocean Modeling System for scientific and operational applications over a wide range of spatial scales from coastal to global. The primary focus is to select the most robust set of options and algorithms for relocatable coastal forecasting systems for the Navy. The system will include state-of-the-art numerical algorithms and subgrid-scale parameterizations, nesting options, adjoint modeling, variational data assimilation schemes, air-sea coupling, interdisciplinary coupled models, extensive web-based documentation and user-support software for model set-up, analysis and diagnostics. The system is intended for massive parallel shared- and distributed-memory architectures.

APPROACH

The framework for TOMS is based on ROMS because of its accurate and efficient numerical algorithms, tangent linear and adjoint models, variational data assimilation, modular coding and explicit parallel structure conformal to modern computer architectures (both cache-coherent shared-memory and distributed cluster technologies). Currently, both ROMS and TOMS are identical and continue improving and evolving. ROMS remains as the scientific community model while TOMS becomes the operational community model.

ROMS/TOMS is a free-surface, terrain-following primitive equations ocean model that can be configured for any region of the world's oceans over a wide range of scales from basin to coastal and estuaries (*e.g.*, Haidvogel *et al*., 2000; Marchesiello *et al.*, 2003; Peliz *et al.*, 2003; Di Lorenzo, 2003; Dinniman *et al*., 2003; Budgell, 2005; Warner *et al.*, 2005a,b; Wilkin *et al.*, 2005). The algorithms that

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comprise the ROMS computational nonlinear (NLM) kernel are described in detail in Shchepetkin and McWilliams (2003, 2005), and the tangent linear and adjoint kernels and platforms are described in Moore *et al.* (2004). ROMS includes accurate and efficient physical and numerical algorithms and several coupled models for biogeochemical, bio-optical, sediment, and sea-ice applications. It also includes several vertical mixing schemes (Warner *et al.*, 2005a), multiple levels of nesting and compose grids, tangent linear model (TLM), representer model (RPM), and adjoint model (ADM) for strong and weak constraint variational data assimilation (Di Lorenzo et al, 2006; Muccino et al, 2006), ensemble prediction, adjoint sensitivity studies (Moore *et al.*, 2006), and Generalized Stability Theory (GST) analysis (Moore *et al*., 2004).

ROMS/TOMS is modular and coded in F90/F95. Several coding standards have been established to facilitate model readability, maintenance, and portability. All the state model variables are dynamically allocated and passed as arguments to the computational routines via de-referenced pointer structures. This code structure facilitates computations over nested and composed grids. The parallel framework is coarse-grained with both shared-memory (OpenMP) and distributed-memory (MPI) paradigms coexisting in the same code. ROMS/TOMS uses NetCDF for input and output data manipulation.

WORK COMPLETED

Since the start of this current award the following tasks have been completed:

1. Added a wave radiation stress term to momentum equations which is important in nearshore processes. The required wave data is either read from the forcing file or obtained from a two-way coupling to the SWAN wave model (Warner et al., 2006).

2. Updated sediment model to include stratigraphy and a couple of bedload transport formulations. The current sediment model in ROMS is described in detail in Warner et al. (2006).

3. Implemented wetting and drying capabilities in ROMS which is essential to model shallow estuarine processes and shoreline evolution (Warner et al, 2006). We are still looking for other alternative ways to incorporate wetting and drying effects.

4. A new NPZD biological model have been added using the formulation proposed by Powell et al. (2006). We also built its associated adjoint model.

5. Developed a weak constraint Physical Space Analysis System (W4DPSAS) data assimilation algorithm which considers errors in both model and observations.

6. Developed an optimal observation driver that can be used in adaptive sampling to examine the most efficient and optimal way to sample a particular ocean region

7. Developed a new stochastic optimals driver in terms of the seminorm of the chosen circulation functional to study the influence of stochastic variations (biases) in ocean forcing.

8. Developed various scripts to process and quality control various types of observations for ROMS 4DVar data assimilation algorithms. The ROMS input observations NetCDF file is designed to expand as new observations are acquired. The NetCDF unlimited dimension, *datum*, is

used to store each observation in space and time. This file also contains information about observation type, survey time, spatial location, and observation error covariance. Since this file is processed sequentially forwards and backwards, all the observation data is stored in ascending time order.

9. Acquired a new web domain name (www.myroms.org) to host ROMS web site. This new domain name is institution independent. It facilitates an active community involvement between users and developers.

10. Established a ROMS developer's weblog (www.myroms.org/blog) to provide detailed technical information about algorithms changes, usage, and bugs.

11. Added a **Webcasts** menu to the ROMS website which contains animated PPT presentations with audio. These presentations can be downloaded and played with Macromedia Flash Player which is available for most operating systems. Currently, we have several lectures about adjoint modeling from the ROMS/TOMS Workshop at Scripps Institution of Oceanography, October 15, 2006. We will continue using this medium in the future for technical documentation and lectures about ROMS.

RESULTS

A new release of ROMS/TOMS, version 3.0, was distributed to over thirty beta-testers around the world on May 15, 2006. This version included all the TLM, RPM, and ADM based algorithms shown in Figure 1. The full version will be released to the entire community as soon as we finish the beta-testing phase, basic documentation, and open source licensing.

The current ROMS/TOMS framework (Figure 1) has been updated to include two-way coupling to SWAN wave model and new adjoint-based drivers. The details of coupling to SWAN are discussed in Warner et al. (2006). Currently, the Modeling Coupling Toolkit (MCT) is used to interchange wave data (height, wavelength, period, direction, bottom orbital velocity, and dissipation rate) and circulation data (sea surface height, currents, and water depth) between SWAN and ROMS. The master driver was generalized so concurrent coupling between ROMS and atmosphere-wave models are possible in the future.

An adjoint sensitivity driver was added to explore the sensitivity of the ocean circulation, in a particular region, to variations on the physical (and/or biological, etc) description of the system. This type of analyses is crucial in data assimilation and adaptive sampling because it provides information about the factors that controls the circulation in the studied region (Moore et at., 2006). A related optimal observations driver was also added for adaptive sampling to help design observational networks and improve ocean prediction. The adaptive observations strategies are based in the sensitivity of ocean forecast to any physical aspects of the circulation. It is similar to the adjoint sensitivity driver, but the tangent linear model is now used to propagate the analysis and determine the optimal location for observations.

A weak constraint data assimilation driver based on the 4D-PSAS approach has been added. The W4DPSAS algorithm is similar to the indirect representer method but with the finite amplitude tangent linear model (RPM) replaced with the NLM. Unlike in the strong constraint case, this algorithm allows errors in the model, boundary conditions, and forcing. The minimization is done in observation space. We are currently fine-tuning this algorithm in the Intra-Americas Sea and Southern California Bight applications.

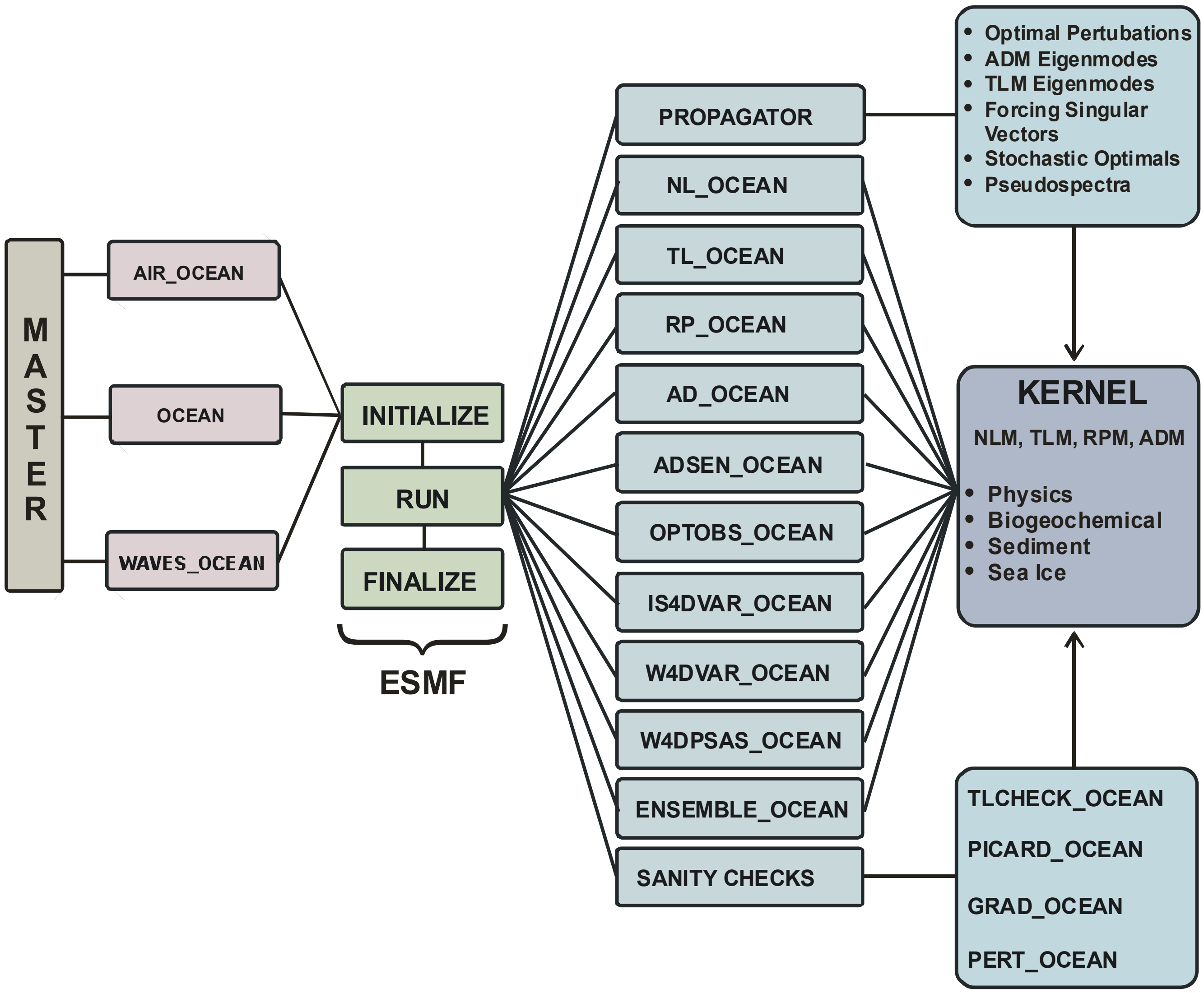

Figure 1: Current ROMS/TOMS framework showing all its computational drivers for numerical ocean prediction.

This summer, the IMCS observational and modeling groups participated in ONR's Shallow Water Acoustics 2006 (SW06) experiment in the Mid-Atlantic Bight. The newly developed ROMS strong constraint, incremental 4DVar algorithm was used, in real-time, to assimilate collected data from several instruments into a regional forecast model of the Mid-Atlantic Bight. This is the first operational application of ROMS 4DVar algorithms in real-time, forecast mode. The data assimilated included observations from gliders, shipboard CTDs, XBTs, Scanfish profiles, shipborne thermosalinograph, daily composite SST, and AVISO gridded altimetry SSH anomalies. The model was forced using NCEP/NAM 3-hours forecasts, Hudson River discharge daily averages, and tidal harmonic components. Since we only have 48-hours of atmospheric data, the data was assimilated sequentially over 2-day interval cycles. The ocean state at the end of the forecast cycle becomes the first guess (background state) for the next 4DVar assimilation cycle. Few plots for the forecast cycle starting on August 24 are shown in Figure 2. The top left panel shows the observations used during this forecast cycle overlaid on the composite SST. The top right panel shows the salinity nowcast at 5m. The bottom panels show cross-sections for temperature and salinity. The model maintained a sharp thermocline at the shelf-front. The low salinity distribution is quite anomalous and it is due to Hudson River discharge; the third highest on record.

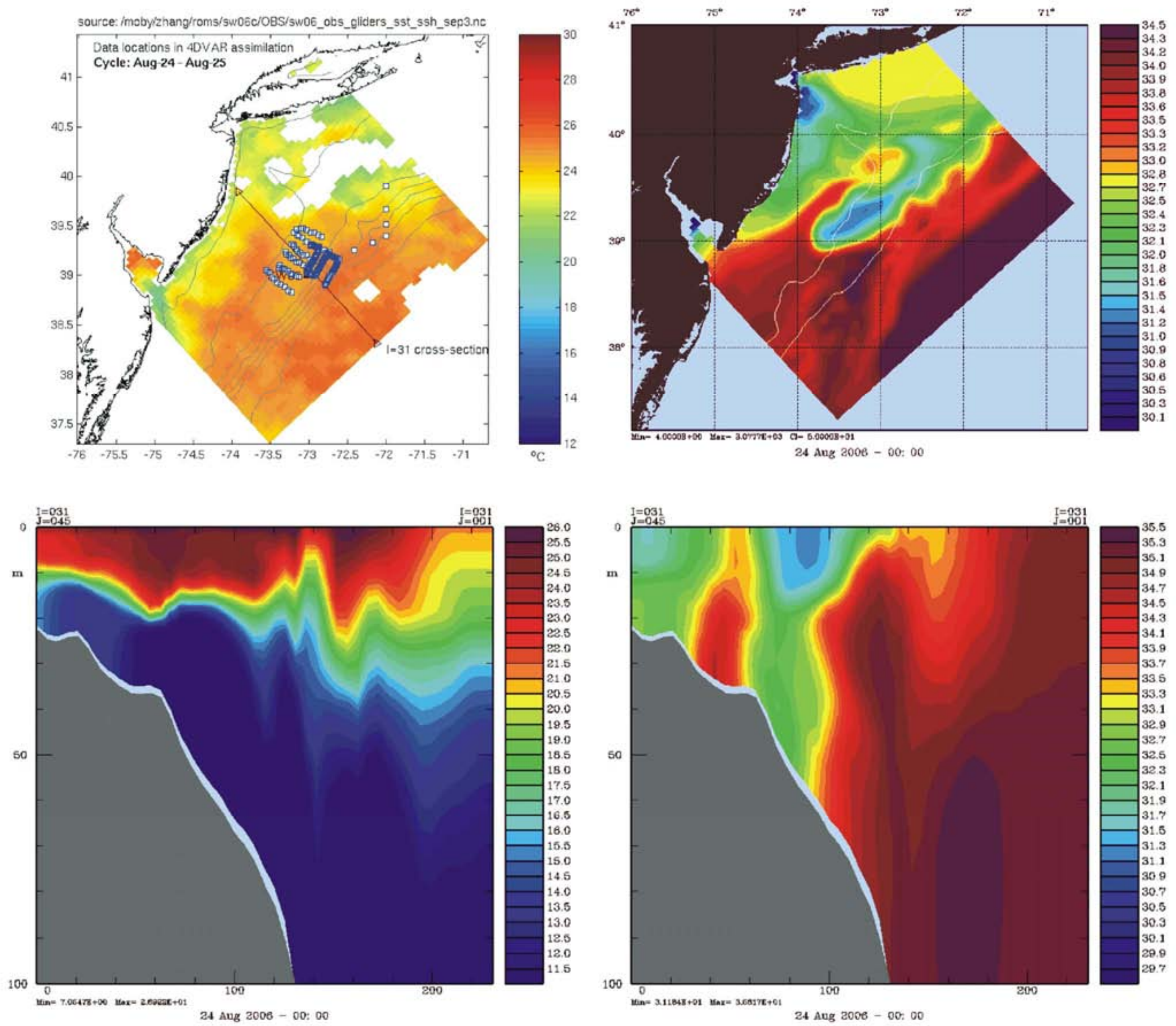

Figure 2: Mid-Atlantic Bight ocean forecast during SW06 for August 24, 2006. Top lef panel shows the location of the observations used in this two-day 4DVar assimilation cycle. Top rigth panel shows the salinity distribution at 5m. Bottom panels show along-self cross-sections of temperature and salinity.

The next ROMS/TOMS workshop will be held at the University of Alcalá, Alcalá de Henares, Spain, on November 6-8, 2006. This is the second ROMS/TOMS European workshop. Currently, there are 75 participants, predominantly Europeans, presenting very diverse and interesting talks. Further workshop details can be found at http://marine.rutgers.edu/po/index.php?model=roms&page=events&id=4.

IMPACT/APPLICATIONS

This project will provide the ocean modeling community with a freely accessible, well-documented, state-of-the-art dynamical and numerical algorithms that can be used to study dynamical process, stability and variability of ocean circulation, prediction, data assimilation, and design of ocean observational networks.

TRANSITIONS

The full transition of TOMS to the operational community is likely to occur in the future. However, the TOMS algorithms are now available to the developers and scientific and operational communities through the ROMS/TOMS website.

RELATED PROJECTS

ONR is currently funding Arango (Rutgers), Moore (U. Colorado), Miller and Cornuelle (Scripps), and Di Lorenzo (Georgia Tech) to develop and test the tangent linear and adjoint versions of ROMS/TOMS. Both the tangent linear and adjoint models can be used for Generalized Stability Theory analysis, adjoint sensitivity analysis, variational data assimilation, and ensemble prediction. These investigators are supported by the following grants:

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